STRATEGY RESEARCH PROJECT

WHAT WILL COMMERCIAL SATELLITE COMMUNICATIONS DO FOR THE MILITARY AFTER NEXT?

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ABSTRACT

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In the eight years from 1995 to 2003, over 890 commercial communications satellites comprising 34 new system constellations will be placed into service orbiting our planet. Many recent studies of the future United States military have identified satellite communications as key to the success of the future force. The military's requirement for command and control on the move (C^2OTM) and its penchant for often deploying to areas where little or no infrastructure exists further validate this satellite communication requirement. Although the military has its own satellite communications systems in use now and planned for the future, those systems have relatively low throughput and therefore do not satisfy the gross future requirements. As military budgets shrink and military constellations wear out without our ability to replace but a very few justified hardened systems, DoD must acquire the best possible mix of satellite communications support for the warfighter via commercial means. The three keys to military success for the

force after next in this dual use area of technology will be: 1) knowledge of our own requirements, 2) knowledge of the technology's limitations, and 3) close cooperation with industry to insure our service specific requirements are met.

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THE FUTURE

It is the year 2020. Army Colonel Buck Powers, commander of the 29th Mobile Strike Force glides toward the foreign battlefield in his command aircraft, a stealth V-22I Osprey upgrade. He activates his command flat panel display and barks at it, "Connect me to the staff!" In moments, the 40-inch color screen display shows the Operations Center conference room with the staff dispersed around the room. Seeing the Colonel on their screen they scramble to take their places next to their briefing panels. "What's the plan?" Powers asks. The 29th's operations officer turns to his board and commands, "Show map." Powers' display alters to the battlefield map overlaid by graphics, with his S2 appearing in a box in the lower right corner. The S2 looks tired, but alert. The intelligence officer rapidly launches through the situation brief and is followed by the S3 with a description of the concept of the operation. The rest of the staff continues on to completion, with the map transitioning to various templates and overlays to display the corresponding threats and plans. Powers feels it's a good plan with just a few adjustments. He dictates those to the S3 and tells him to electronically distribute the plan after the changes are incorporated.

Forty-five minutes later, the pitch of the engines changes as the Osprey transitions to vertical propulsion and into whisper mode as it

closes near to a battlefield overlook. Powers pulls up the final plan graphics and directs his command console to connect him to his battalion commanders. Three boxes appear superimposed on the right of the map screen with the grim faces of his unit leaders. A fourth box appears on the right showing his S3. The operations officer conducts the final briefing and answers the battalion commanders' questions on the operation. Boundaries are clarified and adjusted nearly instantaneously by the S3 on the battle graphics. The briefing concludes and the faces vanish.

The Osprey touches down and Powers drives the remaining distance to the overlook in his command vehicle accompanied by an infantry squad in a 15 ton ceramic armored gun system personnel carrier. He has viewed selected real time video feeds of the battlefield from the Dark Star Unmanned Aerial Vehicle (UAV), but like successful commanders before him, he wants to see for himself. As he nears the overlook, he dismounts with the squad to make his approach. Just prior to the summit he hears a soft tone in his phone earpiece. He touches the side of the earpiece much like a 1997 news journalist and pulls down an screen monocle over his left eye. In the small color screen he sees his second battalion commander, a Marine. Lieutenant Colonel Chesty Fuller explains that his battalion will be delayed getting into position. Powers acknowledges. He again presses the earpiece to terminate the link. After a second press of the earpiece, he hears a tone from the earpiece indicating the communications computer is on

line, he mutters "S3". Ten seconds later, his operations officer appears in the monocle. Powers directs that the S3 resynchronize the attack and publish the order change. He reminds the S3 to insure the air operations officer of the Strike Force validates receipt of the change and to spot check the Air Tasking Order database afterwards to insure that the time change has been incorporated.

THE PRESENT

In the eight years from 1995 to 2003, over 890 commercial communications satellites comprising 34 new systems will be placed into service orbiting our planet.[1] The ongoing explosion of commercial communications satellite system deployments in the next few years will provide an increased array of capabilities and dramatically increased information throughput to the entire world community, especially to those on the move or residing in remote locations with limited infrastructure. Many recent studies of the future United States military have identified satellite communications as key to the success of the future force. Some industry estimates place the potential for Pentagon business at $200 million or more by 2005.[2] This paper critically examines what those planned commercial systems could provide to meet military requirements for the near future and what is needed in the long term for success of the military force after next.

The Defense Science Board (DSB) Task Force on Tactics and Technology for 21st Century Military Superiority concluded recently that the

necessary foundation for a future rapid deployment expeditionary force would be a robust information infrastructure. Not only would the information system provide secure communications to the rapid deployment force of the future, but it would also provide geographical location, precise time, telemedicine and other functions. The DSB logically speculated that the multi-tiered communications network required by the widely dispersed, rapidly maneuvering force of the future would make significant use of geosynchronous and low earth orbit satellites, aircraft and UAVs.[3]

Clearly terrestrial communications systems based on fiber optics cannot accommodate all requirements for constant global connectivity for a highly mobile, split-based air, land, and sea force that will literally have to range the planet for various contingencies in the next 10-20 years.[4] The military's requirement for command and control on the move (C^2OTM) and its penchant for often deploying to areas where little or no infrastructure exists further validate this satellite communications requirement.[5]

Use of commercial satellite communication (SATCOM) systems is not new to the military. Many military personnel who deployed on operations in recent years may have used the communications services provided by International Maritime Satellite Organization Terminals (INMARSAT), the International Telecommunications Satellite Organization (INTELSAT), Alascom, or PanAmSat. Others may have heard of the COMSAT organization. COMSAT is the private U.S. corporation that is

designated as the U.S. representative to the INMARSAT consortium. International consortiums run the INTELSAT and INMARSAT communications systems. The INMARSAT communications are limited to use "for peaceful purposes." The INTELSAT communications are allocated by a United Nations consortium and are governed by not for profit constraints.[6]

MILITARY REQUIREMENTS

Although the military has its own SATCOM communications systems in use now and planned for the future, those systems have relatively low throughput and therefore do not satisfy the gross requirements for military forces of the future. Further, "Department of Defense acquisition timelines cannot keep pace with the rapid developments in SATCOM technology occurring in the commercial arena."[7]

In 1994, Congress required the military to reduce the cost of providing commercial SATCOM support to all Department of Defense (DoD) customers. At the same time, Congress required DoD to plan to provide surge capability to support Joint Task Force (JTF) and related national level missions. That effort, called the Commercial Satellite Communications Initiative (CSCI), acknowledged the military need for protected services and allowed the continuance of limited military SATCOM systems. Therefore, Congress allowed the military to maintain and acquire a small number of special DoD systems to meet specific military requirements. Those requirements include needs for systems

with anti-jam processing, low probability of intercept/low probability of detection, and radiation hardening and survivability requirements.[8]

The Global Broadcast Service (GBS) is a relatively new joint military program begun in 1996 to "…augment and interface with other communications systems and provide a continuous, high-speed, one-way flow of high volume information to deployed, on-the-move, or garrisoned forces."[9] GBS planned service begins with leased commercial broadcast services in 1998 and progresses to a five-satellite military constellation with a maximum capability of 150 Mbps by the year 2000. Warfighter information will be injected into the system via transportable Theater/Tactical Injection Points.[10]

The remaining lion's share of the communications requirement falls to commercial resources to satisfy. The capability was to be provided by a commercially based private network to meet the DoD need for unprotected services. DoD planned to integrate various commercial services, including satellite communications into a virtual private network tied into the Defense Information System Network (DISN) to ensure end-to-end interoperability.[11] The CSCI required the use of unmodified, commercial off-the-shelf (COTS) terminals wherever possible to minimize costs.[12] In 1995, under the provisions of the CSCI, the Defense Information Systems Agency (DISA) contracted for the up to ten year lease of nine commercial C and Ku band transponders.[13]

The 1997 Army SATCOM Architecture reference book is an appropriate start point for a list of follow-on commercial SATCOM requirements for

the future force. It calls for assured, protected, robust communications available to every warfighter on the battlefield. To achieve this goal, the Army cites a requirement for an automated, demand-assigned, bandwidth-assigned on an as-needed basis; SATCOM system. The multi-band, multi-mode, spectrum-efficient constellation envisioned by the Army calls for the following capabilities: 1) simultaneous multi-band two-way transmit and receive functions performed by multiple, simpler satellites; 2) high information throughput in all bands-specifically a requirement for 10 gigabits per second (Gbps) for long-haul trunking means; 3) embedded Asynchronous Transfer Mode (ATM) switching for on-the-fly call routing and efficient processing; 4) interoperability with personal communications or mobile satellite service (MSS) systems; 5) orbits optimized for information throughput with minimum delay; 6) switched cross-links to any communications satellite and airborne communications node in view; 7) virtual "spot beam" for full-time support of low power/small antenna tactical terminals; 8) planar, phased array, high-gain antennas, electrically optimized for each frequency band.[14] The embedded switching could facilitate achievement of the DoD goal of a virtual network, by routing all DoD terminal calls to specific entry points into the Defense Information Systems Network (DISN). Another important and challenging future requirement not mentioned in the Army SATCOM publication, is the need for multiparty video teleconferencing.[15]

The 1997 Defense Technology Area Plan postulates similar goals to include a requirement for providing communications trunks on-the-move (OTM) at 155 megabits per second (Mbps) in the "Long-Term"; long-term meaning sometime after the year 2002.[16] To give a relative measure of what 155 Mbps throughput means to present requirements, one could consider what the currently validated deployed bandwidth requirements are for the Korean Theater. In 1997, DISA validated a 102 Mbps total throughput as what was needed for the deployed JTF, and Navy (including sub-Naval Force elements), Air Force, Army, and Marine forces.[17]

During the Gulf War, the shortfall of a mobile, wide-coverage command and control on-the-move (C^2OTM) system caused commanders to consistently stretch or outrun the capability of their tactical satellite systems. Provision of military mobile satellite service would solve this problem. However, doing this using commercial assets presents unique military requirements for the service provider. In addition to providing the expected global coverage, multi-mode (terrestrial cellular sites and satellite access[18]) capability and long battery life, the system must also protect sensitive user data such as user identification or location. Finally, the system must support military encryption with a phone of comparable size to a commercial cellular telephone.[19]

Based on the requirements above, how well will the deploying commercial SATCOM systems be able to augment those needs in the next six years? The discussion that follows will address all of the

requirements above, but will focus mainly on the three most difficult of the requirements. The most challenging future needs are: 1) the high throughput of 10 Gbps for backbone communications, 2) the requirement for sufficient real time communications throughput on-the-move to support COL Powers' video teleconferencing and situational updates, and 3) the requirement for embedded ATM switching for on-the-fly call routing and efficient call processing.

ASYNCHRONOUS TRANSFER MODE

The military communications community, like the civilian world, generally breaks its types of communications into three distinct categories: voice, video and other data transmissions. The data category includes text, graphics, and imagery.[20] Asynchronous Transfer Mode or ATM is a high throughput communications standard that is in the final stages of its development. ATM was developed because of changes in the nature of data traffic on modern networks and to allow integration of all three types of communication over the same communications channels. Full motion video and other high bandwidth, burst-oriented data transmissions are becoming more popular. Telemedicine is one example of a developing, high priority military video application. Existing communications protocols fail to handle the large bursts of video data transmissions efficiently. The advantage of ATM is that can handle both the short, high bandwidth

transmission bursts as well as the longer, smaller more constant streams of data such as file transfers.[21]

Relative sizes of various types of communications are useful to consider here to appreciate what each requires. Voice communications can be conducted over very small bandwidth channels; 9.6 kilobits per second (Kbps) would be the high-end throughput required for this medium of communication. Current moderate quality video requires at least a bandwidth of 56 Kbps. Some extremely low quality video can be transmitted over 9.6 Kbps channel voice lines. Given this basic understanding of the requirements, a discussion of the characteristics of current and planned commercial SATCOM systems is needed to decide how these systems will best support the military.

GEOS, MEOS, AND LEOS

All of the new commercial satellite systems are not equal. They have different coverage and capabilities engineered to provide appropriate services to their target markets. Based on the satellite locations in orbit and whether they move in relation to a point on the earth causes the systems to have different characteristics. The target services for the commercial satellites include combinations of mobile and fixed station telephony services, paging and messaging services, data, global positioning services (GPS), facsimile services, tracking and monitoring services, television, and video.[22] The orbit location

and number of the commercial satellites in those orbit locations also determine some baseline characteristics of the systems.

Most commercial satellites are placed into two general types of orbits: a geostationary earth orbit (GEO), or a non-GEO classified into one of two general categories: low earth orbit (LEO), or medium earth orbit (MEO). Another term used in lieu of MEO is intermediate circular orbit (ICO). Nordic countries and Russia often use one other type of orbit, called the highly eccentric or elliptical orbit (HEO), but it does not suffice for customers seeking global, constant satellite coverage.[23]

Satellites are further differentiated by whether they act as repeaters (technically called "bent pipe transponders") or if they have on board intersatellite link (ISL) switching and processing capabilities; so called "switchboards in the sky."[24] The ISL concept is new, and not yet completely proven.[25] However, the technology allows the routing that is needed by DoD to specific ground or gateway interface points into the DISN. The space-to-ground links not only fail to merge with DISN entry points, the technology of bent pipe satellite constellations allow the ground entry point used to access the network to also geolocate the service user.[26] For obvious reasons U.S. military users would not want to be geolocated by random foreign service providers; thus creating a high tech version of the Murphy's Law of Combat that says, "Tracers work both ways."[27]

The LEO type is further differentiated in the commercial trade by "little" and "big" appellations based on the services that the communications system provides. "Little" LEO satellite systems provide limited, low-rate data services[28] and were initially intended to provide messaging services to developing nations. "Big" LEO satellite systems provide mobile voice as a primary service in addition to providing data and facsimile transmissions as secondary services through handheld terminals.[29] The handheld terminals are more commonly called personal communications systems (PCS) in the common lexicon of satellite communications vendors.[30]

Finally, the communications throughput of the satellites further separates them into one of two categories: narrowband or broadband. Narrowband satellites generally have voice communication rates of up to 4.8 Kbps and up to 64 Kbps for data. The narrowband satellites target mobile users. Currently planned broadband satellites have uplink data rates of over 2 Mbps and downlink data rates of over 20 Mbps. The broadband satellites focus on fixed station subscribers to provide data transmission for the so-called "Internet-in-the-Sky" or fiberless Internet.[31]

The majority of previous satellite systems such as the INMARSAT, Intelsat, and the military's Defense Satellite Communications System (DSCS) have been GEO satellites. The older GEO satellite systems have acted as radio repeaters. GEO "birds" orbit the earth at a height of 36,000 kilometers above the equator. The GEO satellites circle in

time with the rotation of the planet and essentially retain in the same spatial relationship to specific points on the earth's surface below it. A relatively small number of GEO satellites distributed with minimal overlapping coverage can provide near complete global coverage.[32] INMARSAT and Astrolink GEO systems achieve global coverage with five and nine satellites respectively.[33] Most of the world's major existing telecommunications and broadcasting satellites fall into this category.[34]

Recently, commercial vendors have shown great interest in LEO and MEO systems. The LEO systems orbit at altitudes below 10,000 kilometers and the MEO systems are located from 10,000 to 20,000 kilometers. Because of these systems' closer proximity to the earth, larger numbers of satellites are required to achieve global coverage. For example, to achieve worldwide coverage, the Iridium system requires 66 satellites, the Globalstar system requires 48 and the Teledesic constellation will deploy 288 satellites. MEO systems cut the difference between GEOs and LEOs, by requiring about 20 satellites for global coverage.[35]

COMPARISON OF GEO, MEO AND LEO COMMUNICATIONS

Obviously, one advantage of the GEO satellites is that significantly fewer satellites are required to provide global coverage at a lower cost. Other advantages include the fact that the GEO technology is

proven, whereas LEO constellations are not yet in service and questions remain about some quality of service issues. Due to the height of their orbits, GEO satellites remain in orbit longer, therefore have a longer useful life than the MEO or LEO satellites. GEO satellite lifetimes last on the order of over 15 years in contrast to the LEO satellite lifetimes, which are closer to 5 years.[36] Considering the short life-span of the LEO satellites, the wisdom of relying on commercial vendors to provide access to these constellations rather than have the military deploy and maintain its own satellite network is apparent. The military simply could not afford constant redeployment of a 2.6 billion to 9 billion dollar satellite constellation every 5 years.[37].

GEO satellites are less complex in the respect that they always remain in sight of the same terrestrial gateway. MEOs are overhead for two to four hours, and LEOs only remain in sight of the same ground terminal for about fifteen minutes before handing off to another satellite. The requirement for more satellites to insure uninterrupted coverage for the ground user necessarily complicates and increases the costs of LEO satellite constellations.[38]

However, the new LEO satellite systems are more attractive for real time, interactive system applications due to low transmission latency. Because of GEO constellations' distance from the earth, a half-second delay or "latency" is inherent in all voice transmissions. Many readers may have experienced that delay when making calls over

commercial or military communications routed over a GEO satellite. The delay is irritating and often causes less patient callers to interrupt the person they called. LEO satellites have only one third of that delay. The LEO delay comes very close to the delay inherent in transcontinental terrestrial systems and would naturally make it the system type of choice for military voice and video requirements. One architectural consultant for the Teledesic system claims that since his system will use laser-based ISLs, an around-the-world transmission through Teledesic will be faster than over fiber optic cables on earth. This is based on his assertion that despite the fact that the distance traveled by a signal through space is longer than that on earth, "…light traveling through fiber propagates at around two thirds the speed of light in a vacuum."[39]

Because of the short latency period of the LEOs, they are expected to perform better with interactive applications like voice and videoconferencing. The LEOs are also expected to be able to reuse greater bandwidth amounts than GEOs because of the LEOs more focused radio spotbeams.[40] GEOs appear best suited for non-time sensitive applications such as multicasting, email, bulk data delivery, software distribution, regularly broadcast database updates, and non-interactive video downloads. Another plus for LEO satellites is that for large bandwidth transmissions, they can reach higher rates of transmission faster than GEOS because of this low latency and the way current communications protocols are designed.[41]

It also takes less power for the satellite uplink and smaller antenna size to access the closer LEO satellites. These characteristics allow handset PCS devices[42] rather than the significantly larger suitcase-sized terminals for GEO-based systems. Some GEO systems have reduced their receiver sizes to laptop computer size,[43] but this is still an unwieldy load compared to a handset. This size reduction was achieved by making a higher power GEO satellite transmitter. Lower power GEO satellites are unattractive to the military and other bandwidth hungry users because of the requirement for bulky, non-transportable dishes.

The lower power requirements also allow the LEO satellites to be smaller and less expensive per item than the GEOs. Despite the lower power, because of tightly focused spotbeams, the LEOs can deliver greater bandwidth for reuse.[44]

However, because of the greater number of LEO satellites required for full earth coverage, the LEO constellations are more expensive to maintain, especially because of requirements for in-orbit ready-to-operate spares to insure system reliability and robustness. Another downside to LEO satellites is that because of their higher orbital speed, which is more than twice that of GEO birds, they are more susceptible to destruction from space junk. "Because of their high-speed orbits, a single bolt colliding with a satellite could turn that satellite to worthless liquified plasma."[45] Meteor storms, such as the once-every-30-years event due this summer could cause significant

damage.[46] This may be one reason why Teledesic will not begin launching their system until next year.

MEO systems mainly provide mobile telephony services. The advantages and disadvantages of MEO satellites fall in between those of the GEOs and LEOs.[47]

WHAT CURRENT AND PLANNED COMMERCIAL SYSTEMS QUALIFY FOR MILITARY CONSIDERATION?

Considering the basic military requirements for high throughput global coverage for mobile terminals, multiple, simpler satellites, and orbits optimized for maximum throughput with minimum delay, none of the planned systems through 2003 meet all of the requirements. However, a networked combination of a broadband and big LEO or MEO constellations would come close to the objective requirements. A big LEO constellation would provide C^2OTM voice and low rate data coverage and a broadband LEO constellation would provide state-of-technology high speed, near real-time data service.

Of the 34 commercial SATCOM systems mentioned earlier, three big LEO systems qualify for consideration: Iridium, Globalstar, and the International Communications Organization (I-CO) system.[48] The advantage provided by ISLs to preclude nearby foreign gateway knowledge of unit location and identification rapidly narrows the field to only one system: Iridium.

The Iridium system is a big LEO constellation of 66 satellites with six in-orbit spares and a five-year satellite lifetime. Of the new commercial systems, it is expected to be the first active system with an activation date of 23 September of this year. As of 28 February, 51 of its 72 satellites were in orbit and ten of its 12 planned ground entry points (GEP) or gateways were completed. It initially offers voice, data, paging, and facsimile services at a low transmission rate of 2.4 Kbps. Iridium's target market was business professionals, aeronautical and marine users in addition to the U.S. military which paid fourteen and a half million dollars for its gateway in Hawaii.[49]

Three planned broadband LEO satellite systems make the initial cut for requirements for high throughput broadband communications such as data and high quality video: Celestri, Teledesic, and Skybridge. Skybridge fails to make the cut for ISLs.

Motorola's Celestri plans call for a broadband constellation consisting of 63 LEO satellites with laser ISLs and with nine in- orbit spares linked with up to nine GEO satellites.[50] The system will be in full operation by 2002 and has an eight-year expected lifetime. It promises data rates of up to 155.52 Mbps and states its service objectives as broadband data services including multimedia and point-to-point real-time user communications and fixed voice services.[51] The throughput of the onboard ATM switch is 17.5 Gbps.[52] Celestri satellite coverage includes up to 70 degrees north and south latitude.[53] This qualifies as a global system considering its coverage only omits the

Arctic, Antarctic, Greenland, and the northern-most reaches of Russia and Alaska. One downside to this broadband carrier however, is its current intent to specifically target fixed terminals for large business users. Depending on military interest and vendor willingness, perhaps mobile and transportable applications for their system could be developed similar to the Teledesic system intent mentioned below.

The Bill Gates, Craig McCaw Teledesic constellation is the most ambitious broadband LEO project by far. Their first plans called for deployment of an 840-satellite configuration, and then later they decided to reduce the operational constellation to 288 with 36 in-orbit spares.[54] Teledesic advertises that they can provide data rates from 16 Kbps to 2Mbps on an uplink and from 16 Kbps to 64 Mbps on the downlink.[55] Gateway "Gigalink" terminals between Teledesic satellites and ground networks are expected to have data rates from 155 Mbps to 1.2 Gbps.[56] The system which should be operational in 2002, will provide communications to transportable and mobile terminals such as those on ships and aircraft.[57] The expected data rate for these applications is not specified.

HOW WELL DO THE FRONT RUNNERS MEET THE REQUIREMENTS?

All three systems do well with respect to redundancy and robustness. They include spare satellites to insure continuity of service and have multiple ISLs for alternate routing of traffic.

The Iridium system capabilities have impressed the military so much that the DoD purchased and installed an Iridium gateway in Hawaii. The Army will be buying and providing forty Iridium telephones per division and thirty per corps. The commercial system would not have met the military specific requirements of the DoD without close coordination with Motorola. Specifically, Motorola and QUALCOM are working with the National Security Agency (NSA) to provide a secure cellular telephone. This effort is called the Condor program. In 1999, the first CONDOR Iridium secure handsets will be produced. These Condor telephones will be used to provide C^2OTM to augment the existing single channel satellite systems currently in use to provide command and control. With industry, the military has engineered the Condor telephones to not only be able to complete calls to other secure telephones, but into the Army tactical communications system, and to other secure telephones worldwide in either the DISN or public telephone network.[58]

The Iridium project was obviously a well-coordinated joint effort between the military and industry. In addition to Motorola, the Army is continuing its cooperative efforts to leverage commercial technology for military requirements with ORBCOMM and INMARSAT vendors. ORBCOMM is a little LEO; 28-satellite constellation designed to provide global high availability, low-cost, two-way, on-the-move messaging, email, and facsimile and global position system services.[59]

Although Celestri and Teledesic do not yet tout 10 Gbps long haul trunking capabilities, these systems have the potential to provide the

real-time support required by the military for multiparty video, telemedicine and other applications.

GENERAL COMMERCIAL SATCOM ISSUES

Use of commercial systems today and in the future will not be without problems. The first issue is complexity. Many of the techniques to be used are as yet untested or immature. Some communications analysts are concerned as to whether onboard satellite switching needed to use ISLs will be sufficiently reliable. In addition, the ISLs themselves must be successful for the LEOs to rival their terrestrial optical fiber competition. Related technical issues yet to be solved include jitter and side latency.[60]

Another major problem with the commercial broadband satellite systems being deployed today is a lack of transmission protocol standards. The most significant example of this is the Teledesic system, which will use its own proprietary transmission protocol rather than ATM switching. The failure of the system to use ATM won't preclude military use, but the required translation between the Teledesic protocol and ATM, called tunneling, will decrease system data throughput.[61]

Several costs are associated with satellite systems. Because of the way satellite systems are designed there are wide variances in call costs. While the Iridium system meets military requirements for service, Motorola plans to charge three dollars per minute per call.

Use of Globalstar, a rival big LEO system expects will cost thirty cents per minute - a ninety percent reduction in cost per minute from the Iridium price. Furthermore, the cost for an Iridium telephone is $2500 and Globalstar will charge $1000. The monthly service charge for Iridium telephones, fifty dollars, would be nearly twice that of Globalstar as well. The difference in cost is explained by the techniques Globalstar used to for repeating its signal and the technology it uses for its communications spectrum.[62] One of the reasons that the Globalstar system had lower initial capital costs is that because of its bent pipe transponder technology, it will use local telephone gateways and systems rather than bypassing those systems to go to proprietary entry gateways as Iridium plans. Because of this, Globalstar's capital costs were defrayed by over $300 million dollars by support from foreign service providers who would be reimbursed many times over from charging terrestrial toll costs from their gateways.[63]

One cost estimate showed use of forty Iridium telephones for three hours a day for a year would cost nearly eight million dollars compared to a Globalstar telephone, which would cost about eight hundred thousand dollars! Neither cost is trivial, so military operations and maintenance (O&M) budgets will have to be sufficient to support the costs associated with whatever system the military acquires and uses.[64]

A single point-to-point videoconference can be done respectably by any one of the systems with sufficient bandwidth, but multiparty videoconferencing remains difficult if not impossible. Despite the

tremendous improvement in near real-time transmissions due to reduction of latency, multiparty videoconferencing is not yet specifically supported in any current commercially proposed scheme. Until the vendors include protocols for the native support of group application protocols in the onboard switches of their systems, Colonel Powers' mobile multiparty videoconference aboard his Osprey will not become reality.[65]

One additional area of concern is the use and regulation of the frequency spectrum. Because the Iridium system was designed earlier, it uses a technique called Time Division Multiple Access (TDMA) to differentiate signals by time slot or frequency. TDMA significantly reduces the reuse of that frequency spectrum in nearby communication cells. By contrast, Code Division Multiple Access (CDMA) is a form of spread spectrum communications that differentiates signals by spreading code and allows the use of the same frequencies all of the time, everywhere.[66] Most new systems are using the CDMA technique to insure access to the frequency spectrum in an ever more crowded communications environment. Approval of frequencies by the Federal Communications Commission (FCC) and the International Telecommunications Union (ITU) does not guarantee exclusive use of frequencies worldwide. Some service providers must negotiate with individual nations and their service providers to initiate service in those countries and gain rights to the frequencies.[67]

Another limitation arises for Iridium because of its use of TDMA techniques. The TDMA technology only allows its handsets to "see" one satellite at a time. Rival system handsets using the CDMA technology can combine several weaker signals using a "rake receiver" into an intelligible signal. Iridium and other TDMA systems compensate by using more power, "But no practical amount of power can propel a satellite signal through a tin roof."[68] Higher power requirements translate into either heavier, more expensive satellites or bigger handsets. Teledesic also uses TDMA techniques, but still provides 100,000 times more bandwidth than Iridium. Unfortunately, continued use of the exclusionary TDMA technique may accrue higher political, monetary, and performance costs for using systems.[69]

For a commercial system to merit military investment, it must remain commercially viable. No matter how many qualities that the military desires that a specific system may have, the system must still be successful commercially in its own right. A fairly recent research report shows substantial dissatisfaction among current satellite users who aren't contemplating increasing satellite services and have serious reservations about satellite reliability.[70] However, current expectations for deploying systems are that there is sufficient demand for them. One industry executive predicts that between the year 2000 and 2003 that the Big LEO and up to three regional GEO systems will have over 12 million subscribers.[71]

Other issues that may surface include shortages of launch vehicles and sites, and the previously discussed higher vulnerability of LEOs to space junk.[72]

MILITARY UNIQUE PROBLEMS WITH COMMERCIAL SATELLITES

Business success for commercial systems should be good news, however, if a contingency arises, the military must be able to obtain a surge in bandwidth from appropriate commercial carriers. If the U.S. military fails to reserve bandwidth in advance with a commercial provider and that provider is oversubscribed in a mission area, then military access to enough capacity will be a major issue. In addition, as the number of subscribers in a given region increases, the quality of a commercial SATCOM service would likely decrease. Call completion rates and perhaps circuit quality will decrease with more users and could make assured system access impossible. Warfighters will find it hard to accept busy signals when they are in a time-sensitive, high-pressure situation.[73]

Reserving capacity is the way to go considering that most places our military deploys to involve some sort of natural or human-caused disaster where major portions of the country's infrastructure including fixed communications are destroyed. Without precoordination, available regional satellite communications are likely to be absolutely saturated and would preclude military access. The three year-old, 28 member, Satellite Industry Association, which is an advocacy organization for

the United States satellite industry, will be important entity for military coordination of a Civil Reserve Air Fleet-like capacity in commercial communications.[74]

In recent Army After Next wargames, much has been made of the potential for jamming or the effects of electromagnetic pulses (EMP) on commercial communications. Although commercial systems have some jamming resistance, they lack the beam nulling and signal processing capabilities that give military systems such as MILSTAR the definite edge in jam resistance. Military system spread spectrum techniques give its systems jam resistance, but at the same time this trait reduces satellite capacity because of less efficient use of the frequency spectrum. In addition, radiation hardening and survivability enhancements on the satellites cost more and can further reduce performance.[75]

One more significant commercial cost is associated with what is called "landing rights." Many host nations reserve the right to approve and charge a tariff for operation of any foreign-owned satellite terminal operated within the host nation's borders. Because that country loses potential revenue that would have been gained through use of its own Post, Telegraph, and Telephone (PTT) systems, it charges a license tariff. Even though prior agreements can and have been made to operate systems in host nations, the cost of landing rights can be very high; sometimes as much as ten thousand dollars per terminal. Still other countries such as South Korea require that all

commercial satellite terminals operating in their country belong to South Korea.[76]

Military use of commercial satellites then makes them possible targets of anti-satellite weapons (ASATs). An ASAT makes a satellite inoperable by negating its payload or by physically destroying the satellite. Techniques used by ASATs include "shining" energy on the satellite from a ground or space-based illuminating device and placing co-orbiting mines in space adjacent to the satellite. Another ASAT technique is to make a direct ascent with a high altitude aircraft to achieve co-orbit with a satellite and then to launch a kill device at the satellite. Satellites normally targeted and therefore most vulnerable to ASATs are those in LEO. However, there are more lucrative targets than the planned numerous and redundant LEO communications satellite constellations, such as photographic reconnaissance, weather, and electronic intelligence satellites.[77]

Use of an ASAT weapon by an enemy against a commercial LEO satellite would have to be a desperate measure. Not only would the enemy target our communications, but those of tens of other nations. A ballpark number of new opponents that could be derived from such an attack would probably be close to the number of nations that supported Teledesic's worldwide frequency approval by the FCC. That number was thirty-seven.[78] The attacking nation could also destroy a portion of its own communications support in that attack.

The multinational nature of commercial SATCOM systems may also present problems for the U.S. military in a conflict. Some members of satellite consortiums or important stockholders may object to use of their system for conflict; similar to the provisions of the INMARSAT "peaceful purposes" example mentioned earlier. The military must insure that this limitation is not a possibility when contracting use up front. Despite pre-coordination, if our nation becomes involved in an unpopular military action, international politics may curtail our use of some systems.

Finally, there is a possible catastrophic worst case scenario. While most GEO and MEO satellites may survive the immediate effects of a nuclear airburst; the effects of lingering pumped up ionized radiation belts from the airburst would be deadly to most LEO satellites. Such an act could be plausible for a third world country and it would affect the systems of every world nation that used LEO assets.[79]

According to an estimate by the Electronics Technology Division of the Defense Special Weapons Agency, a 50 kiloton burst over North Korea at a height of 120 kilometers would cause ionizing radiation belts that would probably destroy or disable the entire world's commercial LEO constellation within 55 days. The main problem would not be the electromagnetic pulse of the weapon, but the radiation belts energized by the weapon. The effects of this specific problem can be produced by a nuclear airburst anywhere from 100 to 250 kilometers in altitude.[80]

If this scenario seems implausible at first, consider the thoughts that follow. A third world nation using the weapon could call it a test. The resulting radiation would rapidly knock out any LEO based command and control or other LEO based means of its opponent. The explosion would not necessarily invite direct attack so would not put any significant assets of the protagonist at risk. Admittedly this would not necessarily be a rational act, but often international leaders don't seem to act rationally. This weapon would also have an immediate cost to any nation invested in the technology or who performed significant commerce over those channels.[81]

For just four LEO systems the total cost of replacement of constellations would be over 14 billion dollars and would halt annual sales estimated at 28 billion dollars a year. Even if the SATCOM providers had spares to replace their lost constellations, the residual destructive effects of the slowly abating ionizing radiation last well over a decade and would preclude immediate replacement of any LEO constellation.[82]

CONCLUSION: WHAT IS NEEDED FOR FUTURE SUCCESS?

Obviously an area of special emphasis for military communications over commercial means should include further consideration of whether commercial vendors can economically shield or protect their LEO constellations from the effects of ionizing radiation and what risks the military is willing to take if it cannot mitigate the risk. The

threat from ionizing radiation to GEO and MEO constellations should cause the military to maintain diversification of communications support to preclude over-reliance on LEO satellites. This approach would ensure that the DoD has alternate communications in the case a nuclear burst. Achieving this redundancy will entail higher cost, but the military should continue to balance survivability with minimum communications requirements. DoD must take a hard look at this threat and decide whether the risk is credible and if the current and future military strategic communications capacity is sufficient in such an emergency.

Since past practices of a simple lease of a dedicated transponder are not possible for the non-stationary MEO and LEO constellations, diversification of selection of satellite communications systems to ensure communications are available under all but the harshest conditions may be appropriate. A wise mix of the communications types may be best. Efforts should also be made to lease virtual segments of appropriate systems and to pre-coordinate landing rights corresponding to the systems we will use in anticipated world hot spots.

The military obviously does not have unlimited funds. This reality will force DoD to look hard at tradeoffs for cost efficiencies. One other way to mitigate satellite costs is to insure that less expensive terrestrial means are internetworked with commercial SATCOM systems when possible, as soon as possible.

Technically, the military must watch to ensure some concepts perform as well in the atmosphere as they did on the blackboard, from questions such as whether jitter degrades LEO transmissions, to whether switchboards-in-the-sky are reliable and viable, and finally, whether ISLs live up to their expected performance. We do not yet have ubiquitous 10 Gbps trunks for long haul communications on any system, nor do all systems optimize frequency spectrum or transmission protocols. More work must be done by all of the satellite communications industry to achieve multiparty videoconferencing and the C^2OTM communications rates they provide still fall short of 155 Mbps. Although some solutions will come from increased commercial SATCOM system capacities, other economies will result from further compaction of different media transmissions techniques such as those for telemedicine or video.

As military budgets shrink and military constellations wear out without our ability to replace but a very few justified hardened systems, DoD must acquire the best possible mix of satellite communications support for the warfighter via commercial means. The huge fleet of communications satellites deploying between now and 2003 shows great potential for some, but not all military requirements. The three keys to military success for the force after next in this dual use area of technology will be: 1) knowledge of our own requirements, 2) knowledge of the technology's limitations, and 3) close cooperation with industry to insure our special requirements are met. If we stay

focused on these three areas, Colonel Powers should be able to have his command videoconferences on the move long before the year 2020.

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APPENDIX 1 - ACRONYM GLOSSARY

ASAT	anti-satellite weapon
ATM	Asynchronous Transfer Mode
C^2OTM	command and control on-the-move
CDMA	Code Division Multiple Access
COTS	commercial off-the-shelf
CSCI	Commercial Satellite Communications Initiative
DISA	Defense Information Systems Agency
DISN	Defense Information System Network
DoD	Department of Defense
DSB	Defense Science Board
DSCS	Defense Satellite Communications System
EMP	electromagnetic pulse
FCC	Federal Communications Commission
Gbps	gigabits per second
GBS	Global Broadcast Service
GEO	geostationary earth orbit
GEP	ground entry point(s)
GPS	Global Positioning Services
HEO	highly eccentric or elliptical orbit
I-CO	International Communications Organization
ICO	Intermediate Circular Orbit
INMARSAT	International Maritime Satellite Organization Terminal
INTELSAT	International Telecommunications Satellite Organization
ISL	intersatellite link
ITU	International Telecommunications Union
JTF	Joint Task Force
Kbps	kilobits per second
LEO	low earth orbit
Mbps	megabits per second
MEO	medium earth orbit

MSS	mobile satellite service
NSA	National Security Agency
O&M	operations and maintenance
OTM	on the move
PCS	personal communications system
PTT	post, telegraph, and telephone
S2	intelligence officer
S3	operations officer
SATCOM	satellite communication(s)
TDMA	Time Division Multiple Access
UAV	unmanned aerial vehicle

ENDNOTES

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[2] Pamela Houghtaling, "Agencies Eye Commercial Birds as Interest in Satellites Grows," 11 November 1996; available from <http://www.fcw.com/pubs/fcw/fcwhome.htm>; Internet; accessed 4 April 1998.

[3] Co-Chairmen Donald C. Latham and Theodore S. Gold, "Report of the Defense Science Board (DSB) on Tactics and Technology for 21st Century Military Superiority," memorandum for Chairman, Defense Science Board, Washington, D.C., S-3.

[4] Department of the Army. 1997 Army Satellite Communications Architecture Book, (Fort Gordon, GA: U.S. Army Signal Center and Fort Gordon, 1 April 1997), F-1.

[5] Ibid., 1-6.

[6] Ibid., 9-3 - 9-7.

[7] Ibid., 12-17.

[8] Ibid., 12-18, 9-3.

[9] Ibid., 12-9.

[10] Ibid., 12-11 - 12-12.

[11] 1997 Defense Technology Area Plan for Information Systems and Technology: Seamless Communications, available from <http://www.fas.org/spp/military/docops/defense/dtap/informat/ch030304.htm>; Internet; accessed 1 April 1998, para 3.4.3.1.3.

[12] 97 Army SATCOM Architecture Book, 10-11.

[13] Lieutenant Colonel Rich Tomas, DISA CSCI Manager, "Commercial Satellite Communications Initiative Overview," briefing to the CJCS J6 and Service Counterparts, Feb 1997, 12.

[14] 97 Army SATCOM Architecture Book, 12-18 - 12-19.

[15] "1997 Signal Symposium: Partnership with Industry,'The Big Picture': Keynote Address," Army Communicator vol. 23 no.1 (Winter 1998): 4-6.

[16] 97 Defense Technology Area Plan, fig III.9.

[17] Revised DISN Deployed Bandwidth Requirements PC4AIC 1997, Defense Information Systems Agency.

[18] "GSM Roaming with MSS?" 1997; available from <http://www.cellular.co.za/gsm-mss.htm>; Internet; accessed 30 March 1998.

[19] George Gilder, "Ethersphere," 10 October 1994; available from <http://www.forbes.com/asap/gilder/telecosm9c.htm>; Internet; accessed 4 April 1998.

[20] 97 Defense Technology Area Plan, para 3.4.1.

[21] "Networking in the 21st Century: The Sky's the Limit: GEO-LEO Hybrids: Two Mints in One," 1998; available from <http://techweb.cmp.com/nc/905/905f2side3.html>; Internet; accessed 1 April 1998.

[22] Analysys Consultancy Database.

[23] John Williamson, "New Horizons for Satellite Communications," Available from <http://www.globalcomms.co.uk/ technology/publisat.htm>; Internet; accessed 30 March 1998.

[24] Ibid.

[25] "Networking in the 21st Century: The Sky's the Limit: High Hopes, High Hoops," 1998; available from <http:// techweb.cmp. com/nc/905/905f2side7.html>; Internet; accessed 1 April 1998.

[26] Genard Garcia, "LEOs, MEOs, and GEOs: Family of Mobile Satellite Systems," Available from <http://nic2.hawaii.edu/ ~genardg/leos.html>; Internet; accessed 1 April 1998.

[27] Another concern for our commander of the future will be compromise of his unit position when one or more of his soldiers bring their own PCS phones to the battlefield and use them. The systems with the cheapest airtime charges are the bent pipe systems that will route calls through the nearest gateways, thereby

geolocating the using party (and their unit) for whoever operates that gateway.

[28] "Satellite Orbits," 1997; available from <http://www.cellular.co.za/satellite-orbits.htm>; Internet; accessed 1 April 1998.

[29] Garcia.

[30] "GSM/AMPS/D-AMPS Roaming with GMPCS?" 1997; available from <http://www.cellular.co.za/gsm-mss.htm>; Internet; accessed 1 April 1998.

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[32] Williamson.

[33] Analysys Consultancy Database.

[34] "Satellite Orbits."

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[39] "Networking in the 21st Century: The Sky's the Limit: Do LEOs Have Too Much Latency?" 1998; available from <http://techweb.cmp.com/nc/905/905f2side8.html>; Internet; accessed 1 April 1998.

[40] "...You Say GEO, I Say LEO, Oh My, Oh MEO."

[41] "Networking in the 21st Century: The Sky's the Limit: GEOs Turn Up the Speed of Light," 1998; available from <http://techweb.cmp.com/nc/905/905f2side2.html>; Internet; accessed on 1 April 1998.

[42] Garcia.

[43] Lloyd Wood, "Lloyd's Satellite Constellations," 17 February 1998; available from <http://www.ee.surrey.ac.uk/Personal/L.Wood/constellation/>; Internet; accessed 30 March 1998.

[44] "...You Say GEO, I Say LEO, Oh My, Oh MEO."

[45] "...High Hopes, High Hoops."

[46] Ibid.

[47] "Satellite Orbits."

[48] Analysys Consultancy Database.

[49] Ibid.

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[51] Ibid.

[52] Wood, Cruickshank, and Sun.

[53] Analysys Consultancy Database.

[54] Wood, Cruickshank, and Sun.

[55] Analysys Consultancy Database.

[56] Wood, Cruickshank, and Sun.

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[59] Analysys Consultancy Database.

[60] "...High Hopes, High Hoops."

[61] Wood, Cruickshank, and Sun.

[62] Gilder.

[63] Shillinger.

[64] Shillinger.

[65] Wood, Cruickshank, and Sun.

[66] Gilder.

[67] "...High Hopes, High Hoops."

[68] Gilder.

[69] Ibid.

[70] Ibid.

[71] "Networking in the 21st Century: The Sky's the Limit: Mobile Voice Blazes an Astral Trail for Broadband," 1998; available from <http://techweb.cmp.com/nc/905/905f2side10.html>; Internet; accessed 1 April 1998.

[72] "...High Hopes, High Hoops."

[73] Colonel (Ret.) Robert Forrester, <Robert.Forrester @GSC.GTE.Com>, "Commercial SATCOM Paper," electronic mail message to Gregg Petersen <peterseg@carlisle-emh2.army.mil>, 12 April 1998.

[74] Clayton Mowry, Director, Satellite Industry Association, "Commercial Satellites," briefing to the U.S. Space Architect, 17 April 1998, 2-3. The organization represents manufacturers, service and launch providers. It also has some non-voting international members.

[75] 97 Army SATCOM Architecture Book, 9-3.

[76] Ibid.

[77] Joan Johnson-Freese and Roger Handberg, Space, The Dormant Frontier, (Westport, Connecticut: Praeger Publishing, 1997), 40.

[78] "World Radio Conference Completes Spectrum Allocation for Teledesic's Global, Broadband 'Internet-in-the-Sky,'" 21 November 1997; available from <http://www.teledesic.com/ newsroom/11-21-97.html>; Internet; accessed 30 March 1998.

[79] R. C. Webb, "Nuclear Threats to Low Earth Orbit Satellites," briefing, Carlisle Barracks, PA, U.S. Army War College Center for Strategic Leadership, 23-25 March 1998. The 1.4 megaton STARFISH high altitude burst at a height of 400 kilometers over Johnston Island in 1962 knocked out seven satellites in seven months. For example, the Transit 4B lasted 4 days, the Traac lasted 24 days, the and the Ariel lasted 36 days before premature solar cell degradation. The Telstar satellite lasted seven months prior to premature command decoder failure. The "pumped belts" lasted until the early 1970s. Other LEO environment effects include prompt damage from X-ray, gamma, neutron and thermal pulse, and delayed effects from persistent "debris gammas" in addition to the "enhanced" electron belts.

[80] Ibid. This refers to "unhardened" LEO systems.

[81] Ibid. In addition to LEO communications satellites, the Defense Meteorological Support Program (4 satellites), LANDSAT (2 satellites), NOAA (4 satellites), National Technical Means, Gamma Ray Observatory, Upper Atmospheric Research Satellite, TOPEX/Poseidon, MACSAT, Hubble Space Telescope, International Space Station, Earth Radiation Budget Satellite, and Extreme UV Explorer constellations would also probably be knocked out.

[82] Ibid.

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